Background: 1st Workshop on Mixed Ion Beam Delivery

In recent years, mixed helium–carbon ion irradiation has been proposed as a promising tool for online monitoring in carbon ion therapy [1, 2]. Because $^{4}He^{2+}$ and $^{12}C^{6+}$ have similar charge-to-mass ratios ($q/m \approx 0.5$), they can be simultaneously accelerated in the synchrotron and extracted at nearly the same energy-per-mass. Under these conditions, helium has a range roughly three times longer than carbon, enabling simultaneous carbon ion treatment and helium radiography downstream of the patient (Fig. 1).

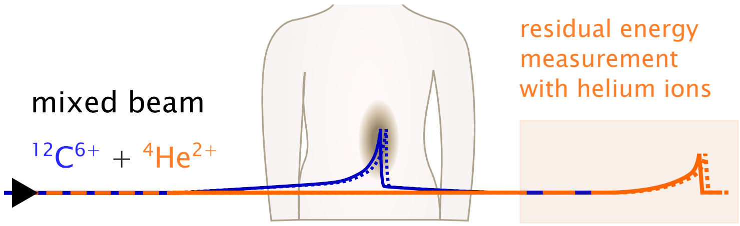

Figure 1: Schematic mixed beam irradiation. The carbon beam is used for tumour treatment while the residual helium energy is measured downstream of the patient for diagnostic purposes.

Over the past two years, the first mixed helium–carbon ion beams with energies of 120 MeV/u to 400 MeV/u have been delivered for initial research projects at GSI and MedAustron. At GSI, a $^{12}C^{3+}/^{4}He^{1+}$ mixture with $q/m \approx 1/4$ was extracted from a single 14.5 GHz ECR ion source and, after acceleration through UNILAC and SIS18, delivered to the biophysics cave [3, 4]. However, current clinical carbon ion facilities cannot accelerate such a $^{12}C^{3+}/^{4}He^{1+}$ mixture through their LINACs, as these require $q/m > 1/3$. To still enable mixed-beam research at the ion beam therapy and research center MedAustron, helium and carbon ions are generated in separate ion sources and only combined in the synchrotron by means of a sequential multiturn injection [5]. As a result, after injection, the two species occupy different regions in horizontal phase space.

After injection, both ion species are captured together [6], accelerated, and extracted using third-integer resonance slow extraction [4, 7]. The small relative q/m offset, $\Delta(m/q)/(m/q) = 0.065\,\%$, introduces additional beam dynamics challenges in the synchrotron, which must be well understood to configure the slow extraction excitations such that a constant helium-to-carbon ratio is maintained throughout the entire 1-10 s spill. At the same time, this small offset in q/m can also be exploited for noninvasive monitoring of the mixing ratio in the synchrotron.

To support these studies, mixed beam detector and beam diagnostic systems are under development, with considerable potential for further dedicated advancement. These include, among others, gas-exchange cell measurements for mixing-ratio identification in the keV/u regime [8], techniques for noninvasive mixing ratio determination in the synchrotron [9], and mixed beam characterization systems for the extracted beam based on ionization chambers [3, 6, 10], scintillators [1], and semiconductor sensors [5].

Further, in accelerator facilities with the option of applying multiple, independent RF frequencies to the synchrotron RF system, simultaneous acceleration and delivery of multi-isotopic beams with unequal q/m ratios is also possible. The two ion species still feature a similar magnetic beam rigidity but different revolution frequencies. Such ability to simultaneously accelerate particles with different q/m opens new possibilities beyond ion beam therapy, e.g. in plasma physics. The first successful demonstration of two-frequency dual-beam ($^{56}Fe^{25+}$ and $^{209}Bi^{68+}$) acceleration was achieved at GSI in May 2025 [11].

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